FLORISTIC DIVERSITY AND DYNAMICS IN THE FARASAN ISLANDS, RED SEA, SAUDI ARABIA

KHALID AWADH AL-MUTAIRI

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By

KHALID AWADH AL-MUTAIRI

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LIST OF ABBREVIATION

ANOVA	=	Analysis of Variance
CCA	=	Canonical Correspondence Analysis
CO_2	=	Carbon dioxide
MG	=	Mangrove
MVSP	=	Multi Variate Statistical Package
NW	=	North west
P	=	presence
RDA	=	Redundancy Analysis
RH	=	Rocky Habitat
SD	=	Standard Deviation
SE	=	Standard Error
SE	=	South east
SF	=	Sand Formation
SLOSS	=	single large or several small reserves
SM	=	Salt March
SPSS	=	Statistical Package for the Social Sciences
WC	=	Wadi Channel

LIST OF SYMBOLS

Symbol		Description
%	=	Percentage
km^2	=	Kilometer Square
Sp	=	Species
m	=	Meter
km	=	Kilometer
‘N	=	Degree north
‘E	=	Degree east
°C	=	Degree Celsius
gm	=	gram

KEPELBAGAIAN FLORA DAN DINAMIK DI KEPULAUAN FARASAN, LAUT MERAH, SAUDI ARABIA.

ABSTRAK

Kajian semasa mengiktiraf kajian intensif ekologi yang pertama yang dijalankan di Kepulauan Farasan berkaitan dengan mekanisme serta proses kepelbagaian dan komposisi tumbuhan. Kajian selidik flora dijalankan di 20 buah pulau, yang berkeluasan daripada beberapa meter persegi hingga 381 km^2 untuk menganalisis komposisi serta kepelbagaian flora. Analisis telah mengenal pasti sejumlah 191 spesies kepunyaan 129 genera dan 53 famili, dengan 38 spesies kepunyaan Monocotyledoneae dan 153 spesies Dicotyledoneae. Famili terbesar ialah Poaceae dengan 27 spesies, diikuti Convolvulaceae, Fabaceae dan Capparaceae dengan 13, 12 dan 11 spesies, masing-masing. Pulau yang besar seperti Farasan Alkabir, Sajid dan Zuifaf mempunyai kepelbagaian flora yang lebih besar daripada pulau-pulau yang kecil seperti North Reef, South Reef dan Sulyn. Terdapat lebih kurang 14 spesies terhad kepada kepulauan Farasan. Perbandingan antara flora yang ditemui dalam kajian ini dengan Saudi Arabia mendapati korelasi yang dekat dari segi taksa dan bilangan mereka. Di samping itu, kawasan kajian mempunyai nisbah spesies-kawasan antara yang terbesar dibandingkan dengan wilayah flora yang lain dinegara tersebut. Flora yang terdapat di kawasan kajian menunjukkan kedominanan yang jelas daripada korotip mono-wilayah (80.1%) yang diwakili oleh pusat endemisme serantau Somali-Masai (34.7%) dan zon serantau Saharo-Sindian (45.44%). Korotip seterusnya termasuklah Pusat Endemisme Nubo-Sindian setempat (27.17%) dan Subzon serantau Arab (18.27%). Dapatan ini menyokong pendapat bahawa flora yang ditemui di barat

dan selatan Arab mewakili rangkaian fitogeografi antara Afrika Timur dengan Asia Selatan.

Perkaitan flora daripada bentuk kehidupan menunjukkan kedominanan terofita (tahunan) adalah bentuk kehidupan yang dominan (28.8%), diikuti oleh kamaefita (27%). Hemikriptofita dan tumbuhan memanjat (terdiri daripada) membentuk 15.2% and 8.7%, masing-masing. Geofita dan, fanerofita adalah sama (10.1%). Geofita dan kamaefita mendominasi habitat masin sementara tumbuhan memanjat, terofita dan hemikriptofita mendominasi pembentukan pasir dan batuan dasar.

Taburan dan pola penzonan tumbuhan dan korelasinya dengan faktor alam sekitar dikuantitikan melalui analisis multivarians dari segi pengelasan dan ordinasinya., Analisis pengelasan dan ordinasi DCA menghasilkan pengenalpastian 12 kumpulan tumbuhan dipunyai oleh lima habitat utama (pokok bakau, kawasan payau, pembentukan pasir, terusan wadi dan batu karang), dan setiap satu komposisi flora tertentu dan ciri-ciri persekitaran tertentu, dan boleh dikaitkan dengan habitat khusus. Analisis Lelebihan (Redundancy Analysis, RDA) dengan pemilihan variabel persekitaran ke hadapan dan dikaitkan dengan ujian permutasi Monte Carlo mencadangkan bahawa kemasinan tanah, bahan organik, kalsium karbonat dan ketinggian adalah faktor utama bagi menerangkan variasi komposisi flora. Indeks kepelbagaian menunjukkan bahawa batu karang merupakan habitat yang paling pelbagai, diikuti dengan pembentukan pasir, sementara, pokok bakau dan saluran wadi mempunyai indeks kepelbagaian yang paling rendah.

Berdasarkan teori biogeografi pulau, jumlah kekayaan spesies tumbuhan dan kumpulan ekologi mereka secara positifnya dipengaruhi oleh saiz pulau, jumlah habitat, ketinggian dan tidak terjejas oleh pengasingan. Tahap kekelompokan yang

tinggi, kesan yang kuat daripada kawasan terhadap jumlah kekayaan spesies tumbuhan dan kumpulan ekologi, dan kesamaan komposisi tumbuh-tumbuhan terhadap pulan mempunyai beberapa implikasi terhadap pemuliharaan.

FLORISTIC DVERSITY AND DYNAMICS IN THE FARASAN ISLANDS, RED SEA, SAUDI ARABIA

ABSTRACT

The current work establishes the first intensive ecological study of Farasan Archipelago concerning the mechanisms and processes of vegetation diversity and composition. The floristic survey was carried out on 20 islands which vary in areas from few square meters to about 381 km^2 to analyze the floristic diversity and composition. The analysis identified a total of 191 species belonging to 129 genera and 53 families, with 38 species belonging to the Monocotyledoneae and 153 species to the Dicotyledoneae. The largest family is Poaceae with 27 species, followed by Convolvulaceae, Fabaceae and Capparaceae with 13, 12 and 11 species, respectively. The larger islands such as Farasan Alkabir, Sajid and Zuifaf are more diverse than the small islands such as North Reef, South Reef and Sulyn. About fourteen species are found to be restricted to Farasan archipelago. A comparison of the flora of the current study with that of Saudi Arabia showed a close correlation of taxa and their numbers. Additionally, The study area has one of the highest species-to-area ratios compared to other regional floras of the country. The flora of the study area showed a clear dominance of mono-regional chorotypes (80.1%) represented by the Somali-Masai regional center of endemism (34.7%) and the Saharo-Sindian regional zone (45.44%). The latter chorotype included the Nubo-Sindian local center of endemism (27.17%) and the Arabian regional subzone (18.27%). These results support the view that the flora of western and southern Arabia represent a phytogeographical link between eastern Africa and South Asia.

The floristic relationship of the life form demonstrated the dominance of therophytes (annuals) were the dominant life form (28.8%), followed by chamaephytes (27%). Hemicryptophytes and climbers constituted 15.2% and 8.7%, respectively. Geophytes and phanerophytes were equally represented (10.1%). Geophytes and chamaephytes dominate the saline habitats, while climbers, therophytes and hemicryptophytes dominated the sandy formations and rocky plains.

The distribution and zonation patterns of the vegetation and its correlation with environmental factors were quantified by multivariate analysis in terms of classification and ordination. The classification analysis and DCA ordination resulted in the recognition of twelve vegetation groups belonging to five main habitats (mangroves, salt marshes, sand formations, wadi channels and coral rocks), each of a definite floristic composition and environmental characteristics, and could be linked to a specific habitat. Redundancy Analysis (RDA) with forward selection of environmental variables and associated Monte Carlo permutation tests suggested that soil salinity, organic matter, calcium carbonates and elevation were the main factors for explaining the variation in the floristic composition. The diversity indices indicated that coral rocks are the most diverse habitats followed by sand formation, while, the mangroves and Wadi channels had the lowest diversity indices.

Following island biogeography theory, total plant species richness and their ecological groups were positively influenced by island size, number of habitats, elevation and were not affected by isolation. The high level of nestedness, the strong effect of area on total plant species richness and ecological groups, and the similarity of vegetation composition on the islands has several implications for conservation.

CHAPTER 1

GENERAL INTRODUCTION

1. 1 The Red Sea Ecosystem

1.1. 1 Geography and geomorphology

The Red Sea separates Arabian plate from Africa (Figure 1.1). Arabia began to split away from Africa with great uplifts on either side of a fissure that developed into the Red Sea. Arabia then became a separate tectonic plate, and the drift away from the African Plate caused crustal thinning with the release of vast lava flows, especially along the uplifted western margin of Arabia. The Red Sea is nearly 2000 km long with a maximum width of about 280 km, and extends from 12.5° N to 30° N (Braithwaite, 1987, Head, 1987). In the north it branches into the Gulf of Suez and the Gulf of Aqaba. Its sole natural link to the world ocean at its southern entrance, the Bab al-Mandab, currently has a maximum depth, at the Hanish Sill, of 137 m (Banaja *et al*., 1990).

Throughout its length, the Red Sea opposing shorelines in Africa and Asia are remarkably parallel. In the north, the width of the sea is only 175 km but southwards it increases to a maximum of 350 km in the area between Jizan (Saudi Arabian coast) and Massawa (Eritrean coast), latitude 16º 55'N, longitude 42º 35'E. From there it decreases to a minimum of 24 km at Bab Al-Mandab Strait (latitude 12º 35'N, longitude 43º 30'E) (Shawar, 1989).

Figure 1.1 Map of the Red Sea and its Separation of African and Arabian Plates.

(Source: Google map).

The land adjacent to the Red Sea is generally mountainous, flanked on the eastern side by high table-land of Arabia and Yemen, and on the western side by a range of mountains 1,705–2,187 m above sea level (Zahran, 2010). A gently sloping plain extends in the deep trough between the shore and the high land. This coastal plain, which varies in width from <8 to >35 km, is covered with sand, over which the drainage system meanders by shallow courses. Along the Gulf of Aqaba (Sinai western side) and in certain parts of the western side of the Gulf of Suez (e.g. Khashm El-Galala, about 60

km south of Suez) the coastal plain is practically non-existing and the mountains rise almost directly from the water of the Gulf (Manighetti *et al.,* 1997).

1.1.2 The Red Sea Island Environments

The majority of islands in the Red Sea are of the continental type since they have been connected to the mainland on several occasions in the geological past (Manighetti *et al.,* 1997, Hubert-Ferrari *et al*., 2003). Continental type islands such as those found in the Red Sea may shed considerable light on ecological processes and human evolution (King and Bailey, 2006, Bailey *et al*., 2007).

The Red Sea contains a complex of islands differing in shape, size, spatial arrangement and distance from the mainland Examples include large relatively isolated islands such as Farasan Alkibir (lies about 50 km west of Jizan, Saudi Arabia) and Nora Island (Dahlak Archipelago, Eritrea) in the south. On the other hand, there are islands lie just off and so close to the mainland, such as Tiran and Kamaran Islands at the northern and southern of the Red Sea. There are large islands with many satellite islets around them (e.g. Farasan and Dahlak). In addition these islands differ in age, isolation, geology and human colonisation history (Bellahsen *et al*., 2003, Hubert-Ferrari *et al*., 2003).

The islands of the Farasan and Dahlak Archipelagos are due to salt diapirism from the underlying Miocene evaporates (Angelluci, 1995), as is Kamaran Island off the western coast of Yemen. Others are of volcanic origin, such as the islands of Jabal at Tayr, Perim, Hanish Al Kabir and Az Zuqur. Tiran and nearby Sinafir islands are relatively

large islands at the approach to the Gulf of Aqaba, both formed by uplifted blocks of Neogene greywacke bordered by coral reefs (Hubert-Ferrari *et al*., 2003, Bailey *et al*., 2007).

The islands present in the Red Sea Basin display a wide range of sizes from a fraction of 1 km^2 (various islets in the Farasan and Dahlak Archipelagos and Yemni coast) to Dahlak Kebir (645 km^2) and Farsan Alkbir (381 km^2). A range of altitudes is also present from sea level to 645 m at Hanish al Kabir. (Hubert-Ferrari *et al*., 2003)

1.1.3 Biodiversity of The Red Sea

The Red Sea is a globally significant semi-enclosed sea area, in terms of its unique biodiversity, species endemism, significance for maritime culture, and its renewable resources (Head, 1987). The Red sea's coastal and marine environment is both diverse and attractive from its rocky and sandy coasts to the saline mud flats, sabkhas, mangrove swamps, coral reefs and sea grass beds, and are key areas of ecological and economic importance (Sheppard *et al*., 1992, Gladstone, 2000).

There is a high importance of the Red Sea globally as a semi-enclosed sea area (Gladstone *et al*., 1999, Tomas *et al*., 2010) for its unique biodiversity, species endemism, significance for maritime culture, and its renewable resources (Gladstone, 2000).

The islands are distinct from the rest of the provinces of Saudi Arabia by the existence of many types of plants that have been not previously recorded in the islands. A 14

species were to be known as a characterization associated with Farasan Islands, also, 69 species of plant were recorded which are used in folk medicine. As for other types of plant life, it was stated by Tomas *et al*. (2010) that there are many types of animals such as deer, foxes and dolphins as an example for Mammals (Masseti, 2010). As for reptiles, there are snakes and turtles. These have had an abundance and great diversity in wildlife a cause to make it a natural reserve where hunting is prohibited throughout the year, except for fishing.

The biodiversity (flora and fauna) in Farasan archipelago is major concern for global diversity and conservation. For instance, Masseti (2010) investigated the faunal diversity of mammals in Farasan Archipelago and found high faunal diversity in the islands of this archipelago. Consequently, Farasan Al-Kabir is a protected area for its unique biodiversity where the only remaining wild population of Arabian Gazelle does exist there (Thouless and ALbassri, 1991). On the other hand, these islands also play an important role for migratory birds as a nesting place and a suitable environment for a number of endemic races of snakes.

The area has the largest population of *Idmi gazelle* in Saudi Arabia. Many species of bat exist, including Patrizi's trident leaf nose bat *Asellia patrizii*. Sea mammals were also found in the coastal waters includeing a small remnant population of dugong *Dugong dugon* and three species of dolphin, *Stenella longirostris*, *Tursiops truncatus* and *Stenella attenuate*. Humpback whale *Megaptera novaeangliae* and minke whale *Balaenoptera acutorostrata* have also been reported in the waters of the archipelago (Hall *et al*., 2010). Other prominent animal species include the globally endangered

green turtle *Chelonia mydas* and the critically endangered hawksbill turtle *Eretmochelys imbricate*. More than 145 bird species have been found from the Farasan Archipelago, and the Farasan Islands are listed as an Important Bird Area (Evans, 1994). Two of the most significant bird species are the pink-backed pelican *Pelicanus rufescens* and the osprey *Pandion haliaetus*. Nearly 40 breeding pairs of pelicans live on the islands, which is likely to be the largest breeding colony of this species in the whole of the Red Sea. With more than 42 breeding pairs of osprey the Farasan population is the largest population of this species in the Middle East (Hall *et al*., 2010).

The floristic diversity is very high in Farasan archipelago. For instance Al-Zahrani and El-Karemy (2007) reported a new succulent Euphorbia (Euphorbiaceae) species from Farasan Archipelago. Tomas *et al*. (2010) revealed that the flora in Farasan Archipelago is very diverse. Some of these plant species are great interest in scientific and medical research. In the ecological point of view, the plant communities in this archipelago are interesting as the species occur in an independent environment where influences from other similar communities found in the mainland are minimal (El-Demerdash, 1996). Typically, some key factors are known to affect the growth of annual vegetation in these islands including the occasional rains, condensation of dews or underground water sources. The highest density of the vegetation is observed in the sheltered wadis characterized with fine silty-clay. The southeastern area of Farasan Al-Kabir, is rugged and has the highest number of plant species, whereas the northwestern unbroken plateau and the western encountering the shoreline are poor of plants except for a few annual species (El-Demerdash, 1996, Tomas *et al*., 2010). A reasonable number of vascular plants are halophytes or semi-halophytes and the growth of these plants is influenced by

the salinity of the soil and the distance to the seashore. In the shoreline of Farasan and Sajid islands, the vegetation is dominated by *Avicennia marina* whereas in Zifaf and Dumsuq islands another mangrove species, *Rhozophora mucronata* is present. The sandy beach is dominated primarily by halophytes such as *Limonium axillare, Suaeda monoica, Halopeplis perfoliata, Zygophyllum* sp., *Aeluropus lagopoides* and *Cress cretica* (Alwelaie *et al*., 1993).

However, the first and foremost important factor that makes Farasan group of islands unique is the presence of two important Mangrove species, *Avicennia marina* and *Rhizophora mucronata* (El-Demerdash, 1996). These two species are ecologically important and highly productive littoral biotopes and are acting as a reservoir and refuge for many small animals, birds and fish. The pneumatophores that grow above water are an ideal site for the breeding of a number of fish, particularly of shrimps, prawns and crabs. Both species share the same shore-line habitat and seen growing side by side. Though intermixed with each other, *Rhizophora mucronata* can be easily told apart from the other by its shiny, dark green leaves.

Conservation of biodiversity in all the Red Sea Basin's ecosystems is important for scientific, naturalistic, and cultural reasons. In addition, biodiversity is a source of economic and social resources. Particularly, biodiversity must be conserved in the islands due to insularity and specific constraints (Doak and Mills, 1994). In these islands, animal, vegetal and microbial species are selected and adapted to live in extreme conditions during millenia. Frequently in these ecosystems biodiversity loss is coupled

with serious economic and social impacts compounded by the fragility and vulnerability of the islands (Brown and Lomolino, 2000).

During last decades, *Prosopis juliflora* has been introduced to Farasan island as an ornamental plant. This plant spread beyond the cultivated area and invaded other areas in the island Alkabir. This tree is documented to be a strong competitor in Texas and Oklahoma rangelands where it naturally grows and improve rangeland productivity (Pasiezcnik *et al.*, 2001). The attention over invasion is due to its competition with native plant species for water resources and nutrients. *Prosopis juliflora* roots can grow deeply up to 52 m to access the underground water resources, so it has the ability to endure dry conditions (Al-Humaid and Warrag 1998, EI-keblawy and AL-Rawai, 2007).

The importance of the Farasan Archipelago from a phytogeographical point of view may be due to its position in the Red Sea, which is located in the intersection of the four phytogeographical regions: Saharo-Arabian, Sudanian, Tropical and Mediterranean (Le Houérou, 2003, Al-Nafie, 2008). In addition, it is located at the boundary between the dry and relatively moist south western parts of the country. This boundary has changed its position as part of global climatic changes, several times since the Miocene Era (Dabbagh *et al*., 1984).

Despite the importance of Farasan Archipelago for wild life and biodiversity within the Red Sea ecosystem, detailed ecological studies such as floristic distribution and its environmental correlates, island biogeography and community nestedness are lacking. Recently, island biogeography theory and nestedness are considered as two relevant and

important concepts in biogeography and conservation in the study of archipelagos. Island biogeography has been pivotal in the study of vegetation composition and diversity because archipelagoes provide natural model systems for investigating patterns of diversity and processes that shape ecological communities (Rosenzweig, 1995). On the other hand, analyses of community nestedness, a pattern of composition where species at sites that contain fewer species form subsets of species found at richer sites, aim to determine whether deterministic or stochastic processes shape community structure (Atmar and Patterson, 1993, Patterson and Atmar, 2000). Analyzing patterns of nestedness may offer potential insights for conservation by identifying species at risk of extinction across fragmented landscapes (Moody, 2000), but these inferences are dependent on understanding the underlying mechanisms (Donlan *et al*., 2005).

General overviews of the vegetation have been given for the three main inhabited islands, namely Farasan Al-Kabir, Sajid and Qummah (Alwelaie *et al*., 1993, Hassan and Al-Hemaid, 1996, Al-Farhan *et al.*, 2002). However, little consideration has been given to the vegetation distribution and structure, especially on the uninhabited islands (about 36) and their ecological implications. Except for the work of El-Demerdash (1996) on the above mentioned three inhabited islands, no detailed quantitative analysis has been undertaken. Furthermore, no studies have been carried out for investigating patterns of diversity and processes that shape vegetation communities. The inaccessibility and rugged topography of the Farasan Islands have resulted in a paucity of studies on its vegetation and no complete survey of the flora. Therefore, the present work provides a valuable baseline for understanding factors important in shaping

vegetation communities that will hopefully aid in future efforts for conservation of biodiversity in the arid, fragile and diverse archipelago of Farasan.

1.2 Objectives

This study was conducted to achieve the following objectives:

1- To provide a detailed floristic analysis in terms of encountered families, phytogeography, and life and growth forms.

2- To assess the spatial distribution of vegetation in relation to environmental factors in the different habitats.

3- To evaluate the effects of island characteristics on plant distributions and community structure.

4- To investigate the ecological mechanisms related to the observed pattern of floristic diversity and nestedness that can contribute for conservation of biodiversity in this archipelago.

CHAPTER 2

LITERATURE REVIEW

2.1 Plant Community Composition

There are two broadly conceived research methods dealing with the understanding of the relationships of plant communities to one another and to the environment. These are classification and ordination (also called gradient analysis) (McCune and Mefford, 1999, Leps and Smilauer, 2003, Kent, 2011). Plant communities are rich, dynamic entities; their diversity, composition and spatial scale of variation, i.e., their structure, are driven by a range of factors. These factors, such as variation in abiotic conditions, human impacts, disturbance and predation have been studied since the 1800's across different landscapes, countries, and environmental conditions (Abd-ElGhani and Amer, 2003, El-Wahab *et al*., 2008, El-Bana *et al*., 2010).

2.1.1 Vegetation Classification

Vegetation is often chosen as the basis for the classification of terrestrial ecosystems because it generally integrates the ecological processes acting on a site or landscape more measurably than any other factor or set of factors. Because patterns of co-occurring plant species are easily measured, they have received more attention than those other components, such as fauna. Vegetation is a critical component of energy flow in ecosystems and provides habitat for many organisms. In addition, vegetation is often used to infer soil and climate patterns. For these reasons, a classification of

terrestrial ecological communities based on vegetation can serve to describe many facets of ecological patterns across the landscape.

The structure of plant communities was widely debated throughout much of the century. Essentially, two general models were proposed: the community as discrete unit, and the continuum. The community-unit hypothesis formulated by Clements (1936) states that communities are highly structured, repeatable and identifiable associations of species controlled by climate. The alternative continuum model of Whittaker and Curtis states that plant communities change gradually along complex environmental gradients, such that no discrint associations of species can be identified. Whittaker (1973) wrote of the development of the American Tradition with the debate of the "unit" versus the "continuum" concept. Cowles (1899) and Clements (1905) advocated vegetative organization made up of discrete units of similar vegetation (associations). According to Whittaker, these units were climax communities adapted to the "climates of geographic regions". The American Tradition developed from the unit concept of vegetation organization to the continuum concept, initially advocated by Gleason (1926). The continuum concept places vegetative species independently along environmental gradients.

Continua of independent species distributions revealed in gradient analyses have generally been interpreted as evidence for Gleason's concept of individualistic species assemblages (Gleason, 1926) and this concept has been organized into the individualistic-continuum theory (Goodall, 1963). However, while the continuum model grew out of Gleason's essays on the individualistic distribution of species they

should not be considered synonymous. The individualistic hypothesis is a species-scale phenomenon involving the tolerance of individuals of different species to local environmental conditions, which may include interspecific interactions. In contrast, the continuum model is a community-level construct of the collective distributions and abundance of species along environmental gradients. It is therefore possible, that individualistic distribution of species gives rise to discrete communities as well as to continuum (Collins *et al*., 1993).

Although most ecologists and vegetation scientists now accept the continuum model to be correct, the debate concerning the validity of these models still continues (Callaway, 1997). Westman (1990) suggested the debate endures because empirical evidence exists that supports both points of view. On the other hand, Shipley and Keddy (1987) determined that neither model applied to species distributions along complex environmental gradients in wetlands. Roberts (1987) suggested that both the community-unit and continuum models were consistent with a mechanistic view of vegetation development. From a hierarchical perspective, the two models are not competitive, rather, they reflect differences in scale of perception.

2.1.2 Development of Classification Techniques

Historical insight was important to understand the role of classification in this study. A further review of more recent literature was done to decide which classification method would be used in this study. "Classification techniques used in community ecology may be considered in three groups: table arrangement, hierarchical, and nonhierarchical classification (Gauch, 1982).

Braun-Blanquet (1932) initiated the table arrangement method. The table arrangement approach orders samples-by-species data by placing samples and species into an order that best illustrates community organization. Similar species listed are placed together, dissimilar species are placed apart. Braun-Blanquet based classification on the differential species in the communities. Whittaker (1973) said the Braun-Blanquet method: "...is the most widely applied and most effectively standardized of all approaches to classification, and has been adapted to diverse kinds of vegetation." Although this method is widely used, it has the following limitations: Ecologists need to be trained for the method; It is fairly subjective; and It is not suited for large data sets.

Gauch (1982) stated nonhierarchical classification places similar samples or species into clusters. These clusters demonstrate no inherent relationships between each other. Gauch further suggested nonhierarchical classification should be used as an initial clustering for large data sets to reduce outliers and redundancy. Hierarchical classification also puts similar samples or species into groups (as in the nonhierarchical method), but the groups are also arranged hierarchically. The hierarchy indicates relationships among the groups. Gauch described three methods of hierarchical classification: monothetic divisive, polythetic agglomerative, and polythetic divisive.

The monothetic divisive approach starts with all plots in a single cluster and then divides them into groups based on presence or absence of a single species (monothetic = 1 species). Hill *et al*. (1975) stated that the monothetic divisive method of association analysis "makes far too many misclassifications". Polythetic means information on greater than one species is used. In the polythetic agglomerative method, information on

more than one species is used. It starts out with each plot in its own cluster and systematically links the plots together on the basis of similarity or other criterion. Agglomerative hierarchical methods are bottom-up approaches that generate clusters by sequentially merging pairs of clusters that are closest to each other.

The polythetic divisive method also uses information on more than one species. The plots start out in one cluster and are subsequently subdivided into groups. Divisive method constructs the classification from the top to the bottom. They begin with all samples in a single cluster that is successively divided until individual sites are separated. One of the most popular hierarchical divisive techniques in community ecology, Two-Way INdicator SPecies ANalysis (TWINSPAN) (Hill, 1979), uses this approach. The TWINSPAN algorithm starts with an ordination of samples along the first axis of correspondence analysis (CA) (Hill, 1973). Samples are then divided into two clusters by splitting the first CA axis near its middle. Site classification is refined using a discriminant function that emphasizes species preference to one or the other half of the dichotomy. This process is repeated in the same way for the two clusters. A limitation of the original algorithm was that the number of clusters of the final classification cannot be set manually, but increases in powers of two except when a cluster is too small to be further splitted. TWINSPAN was recently modified by Rolecek *et al*. (2007) to allow any number of terminal clusters. The proposed modification does not alter the logic of the TWINSPAN algorithm, but it may change the hierarchy of divisions in the final classification. Thus, unsubstantiated division of homogeneous clusters are prevented, and classifications with any number of terminal clusters can be created.

The TWINSPAN program creates a "tabular matrix arrangement which approximates the results of the Braun- Blanquet tablework" (Gauch, 1982). TWINSPAN incorporates two of the three basic methods of classification. It is hierarchical and includes a tablework arrangement. Gauch also said TWINSPAN is objective as compared to the subjectivity of the Braun-Blanquet tablework method. From the literature review it was determined that the hierarchial polythetic divisive method and the program TWINSPAN would be used for classification in this study.

In the recent years, community ecologists have applied plant community classification by TWINSPAN in the arid regions of the Arab countries (Shaltout *et al*.,1996, Abbadi and El-Sheikh, 2002). These classifications place plant communities into units such as habitat types or plant associations. Additionally, vegetation studies on islands of the Arab countries such as Khedr and Lovett-Doust (2000), El-Bana *et al*. (2002), Shaltout and Al-Sodany (2008) have used the TWINSPAN program for vegetation classification.

2.1.3 Vegetation Classification along the Red Sea Coast of Saudi Arabia

The literature was also consulted to determine whether or not there were any existing classifications for the vegetation of Farasan Archipelago, or if any of the classifications for the surrounding areas. Abulfatih (1992) surveyed vegetation along an altitudinal gradient up to 3000 meters in southwestern Saudi Arabia. Hegazy *et al*. (1998) analyzed this gradient for vegetation composition, species diversity and floristic relations. Alwelaie *et al. (*1993) provided some information on the communities for a few species on some islands along the Red Sea coast of Saudi Arabia. El Karemy and Al-Zahrani (2000) mapped vegetation on Tawila nd Ghurab Islands along the Saudi Red Sea coast.

This study was a classification, surveyed the vegetation on other four islands (Jabal Sabaya, Um Al Qamari, Al Aghtam and Sequala), and recorded 71 species with 33 families. Al-farhan et al. (2002) developed a checklist of vascular plants on Farasan Archipelago. However, all of these studies are descriptive and without any elaborating of the data.

A quantitative vegetation study of Farasan islands was completed by El-Demerdash (1996). This study concentrated on the vegetation of the three large inhabited and disturbed islands. El-Demerdash provided insight into the existence of seven plant communities that related to seven habitats. There was no detailed existing plant association classification for Farasan Archipelago prior to this study.

2.1.4 Vegetation-environment relationships

The main aim of studies dealing with vegetation-environment relationships is to reveal underlying ecological processes, resulting in appearance of given vegetation pattern in nature. The role of factors such as climatic conditions, human disturbances including, grazing, fire, land clearance and fencing and the abiotic environment including, moisture, temperature, nutrients, topography, slope and seed soil bank are seen as deterministic factors and are thought to playa driving role in structuring plant communities (Crawley, 1997, Hegazy *et al*., 2007, Zahran, 2010). Moisture is often one of the major factors affecting plant community composition. Moisture may be affected by the soil type, soil depth, soil water holding capacity, atmospheric temperature, wind and altitude. Soil moisture content will affect mycorrhizal fungus, associations, soil pH, soil nutrients and invertebrates (Wardle, 1991).

Topographic gradients affect soil fertility and soil depth and thereby plant community composition. Soils in valleys and on the lower slopes are generally deeper and nutrient rich when compared to soils on higher slopes (Bartha *et al*., 1995). In addition the area that a plant community occupies and the distance to other plant communities are two other key factors that can affect the plant community structure (Kent and Coker, 1996, Del Moral, 1999).

All these environmental conditions are often important determinants of community structure and should be considered as they may affect the plant species that are present within a plant community. Although similarities are found among communities in similar environmental conditions, each plant community is unique to the place in which it occurs (Kent *et al*., 1997, Kent, 2011). This multitude of mechanisms that can affect plant communities makes the study of the processes that cause the structure of a given plant community interestingly complex.

Descriptive studies can untangle only correlative, i.e. not necessarily causal links in the vegetation-environment relationships, as the latter are domain of experimental studies designed to separate the effect of the given environmental factor from the others. Still, inference based on descriptive studies is valuable, as it brings important insights into the potential processes. One of the most influential revolutions in vegetation ecology during the last century was development of direct and indirect ordination analysis (McGarigal *et al*., 2000, Leps and Simular,2003, Kent, 2011) Vegetation ecologists got a tool, allowing them to quantify the gradient-related patterns in vegetation, which are observed in the field but difficult to formulate in a non-verbal way. Fast development of

computation power has resulted into today's situation when ordination analysis has become a standard for studies dealing with description of vegetation-environment relationships. However, there are still methodological challenges waiting to be solved, and recent state resembles situation of a wanderer at the crossroad: where to go, further or back?

2.1.5 Vegetation Ordination

Ordination is a collective term for multivariate techniques which adapt a multi-dimensional swarm of data points in such a way that when it is projected onto a two dimensional space any intrinsic pattern the data may possess becomes apparent upon visual inspection (Pielou, 1984). Basically, ordination serves to summarize community data (such as species abundance data) by producing a low-dimensional ordination space in which similar species and samples are plotted close together, and dissimilar species and samples are placed far apart.

Generally, ordination techniques are used to describe relationships between species composition patterns and the underlying environmental gradients which influence these patterns (asking, what factors structure the community?). Recently, use of ordination techniques have expanded to include analysis of dietary overlap (Schluter and Grant, 1982), and to explore patterns of within species morphological differences with geographic distance between populations (Alisauskas, 1998).

There are several ordination techniques, all of which differ slightly, in the mathematical approach used to calculate species and sample similarity/dissimilarity (Kent *et al*., 1997,

Kent, 2011). In 1951, Curtis and Mcintosh 1951 developed the ‘continuum index’, which later lead to conceptual links between species responses to gradients and multivariate methods. Shortly thereafter, Goodall (1963) introduced the term ‘ordination’ in an ecological context for Principal Components Analysis (PCA). Bray and Curtis (1957) developed Polar Ordination (PO), which became the first widely-used ordination technique in ecology. Austin (1968) used canonical correlation to assess plant-environment relationships in what may have been the first example of multivariate direct gradient analysis in ecology. In 1973, Hill introduced Correspondence Analysis (CA), a technique originating in the 1930’s, to ecologists. Correspondence analysis gradually supplanted polar ordination, which today has few practitioners. Prentice (1977) independently discovered and demonstrated the utility of Kruskal’s (1964) Nonmetric Multidimensional Scaling (NMS), originally intended as a psychometric technique, for community ecology. Hill (1979) corrected some of the flaws of Correspondence Analysis and thereby created Detrended Correspondence Analysis (DCA), which is the most widely used indirect gradient analysis technique today. The software to implement Detrended Correspondence Analysis, DECORANA, became the backbone of many later software packages. Gauch’s (1982) book "Multivariate Analysis in Community Ecology" described ordination in non-technical terms to the average practitioner, and allowed ordination techniques to enter the mainstream. Fuzzy set theory, introduced to ecologists by Roberts (1987) is a promising approach with ties to polar ordination, but has yet to gain many adherents. Ter Braak (1986) ushered in the biggest modern revolution in ordination methods with Canonical Correspondence Analysis (CCA). This technique coupled Correspondence Analysis with regression methodologies, and provides for hypothesis testing. Ter Braak and Prentice (1988)

developed a theoretical unification of ordination techniques, hence placing gradient analysis on a firm theoretical foundation. Indirect ordination (DCA) and direct gradient ordination.

During the last decades, the ecologists in few Arab countries have applied DCA and CCA in their studies of vegetation environment relationships (Shaltout *et al*., 1996, Hegazy *et al*, 1998, Khedr and Lovett-Doust, 2000). However, the application of such multivariate analysis is very recent and is still inadequately known for the ecological studies in Saudi Arabia.

2.2 Island Community Composition

The idea of the island laboratory initiated by the works of Charles Darwin (1859) on species and ecosystems was followed by Evans (1977) for humans and early societies. Islands are thus judged as natural laboratories and provide a foundation for the study of natural and cultural processes (Patton, 1996, Whittaker and Fernández-Palacios, 2007). Insularity is truly a limiting factor to resources, allowing hence scientists to study the ways in which biological or human communities have adapted to their environment. This limiting factor generates a self-contained microcosm, almost a closed system, with defined boundaries. This sets islands apart from the contiguity of the continents and thus defines a laboratory of manageable and quantifiable proportions.

Due to their geographical isolation and small size, island ecosystems have a unique evolutionary history. Island ecosystems are fragile and are vulnerable to ecological and anthropogenic changes. Islands usually have lower habitat diversity, higher endemism

and fewer species than comparable mainland areas, the extent of the differences depending on the time the island has been separated from the mainland and the extent of human disturbance (Wright and Cameron, 1990). There are disadvantages directly related to the physical environment of the islands, e.g. restricted resources including land, water, energy, coastal erosion, marine and coastal pollution.

Islands frequently retain natural values that have been lost elsewhere due to the water barriers that separate them from the mainland. Islands are refuges for many plant species as they frequently possess species that are now largely, or entirely, confined to them (Millar and Gaze, 1997, Whittaker and Fernández-Palacios, 2007). These plant species have undergone a strong selection process to survive and therefore are better suited genetically to the habitat (Maunder *et al*., 1999).

Anthropogenic and stochastic events on islands cause changes in plant species composition and richness. The nature of these changes depends on the environmental conditions present on the island, and how those conditions have changed over time. It has been stated that island populations are at greater risk of extinction than those found in continental areas (Whittaker, 1998). There are several explanations for this gloomy trend. The most obvious is the greater susceptibility of island populatios to perturbation from alien plants, animals, pathogens, as well as humans. The sensitivity of island taxa to alien species is due to their evolution in isolation from such perturbations as aggressively growing plants, herbivorous animals, etc. (Carlquist, 1980). Rare plants, endemic to islands have an added risk of extinction because of the extremely reduced numbers of individuals and populations. Such small populations put a species at risk for

several reasons. First, small populations are more susceptible to demographic and environmental stochastic events (Pimm *et al*. 1988, Mills and Smouse, 1994). Environmental occurrences (e.g. periodic drought) and demographic stochasitic events have a more marked effect when populations are small. However, there is evidence suggesting that the genetic characteristics of small populations have a greater effect on the survivability of a population than demographic or environmental stochastic events (Frankham, 1998).

2.2.1 Species Diversity and the Island Biogeography Theory

There exists a copious body of literature pertaining to the study of biodiversity and island biogeography, largely inspired by the work of MacArthur and Wilson (1967). Interest in their theory has generated thousands of papers that have far reaching applications, from reserve design to emerging principles in metapopulation biology and other allied fields (Hubbell *et al*, 1999). Species richness is the fundamental measure in biodiversity and is simply the number of species per sample unit at a given time (Magurran, 2004).

Some of the most widely applied principles in island biogeography attempt to explain variations in species richness among island biota based on relations of spatial scales to immigration, extinction, birth and death rates (MacArthur and Wilson, 1967).

MacArthur and Wilson's theory (1967) set out to identify and measure the variables involved in the colonisation of islands by biota and their subsequent evolution or extinction. The key biogeographical variables identified by their theory were island size

and distance from the mainland. They suggested that an island's biodiversity is proportionate to the island's size (i.e. the larger the island the higher the species number) and inversely proportionate to its distance from the mainland (i.e. more remote islands tend to support less species). Equally significantly they argued that the number of species on an island is in a state of *dynamic* equilibrium – diversity eventually stabilises but turnover remains high as species continually colonise and go extinct.

MacArthur and Wilson's island biogeography theory was based on three intuitive principles: 1) A positive relationship exists between equilibrium species richness and island area as the following equation:

(1) $\log S = \log C + z \log A$,

where log S is species richness, A is island area, C is a constant that varies ng taxa and with unit of area measurement, and z is a constant that typically lies between 0.15 and 0.40.

(2) All things being equal, an inverse relationship exists between species richness and distance to source propagules.

(3) Given a newly-formed island, species diversity will increase with age to a point of equilibrium (or species saturation), at which time the colonization curve will plateau.

Thus, important predictors for island diversity are island size, proximity to seed sources, and age.

Although many studies have demonstrated the relationship between richness in certain taxonomic groups and area, it is widely accepted that area per se does not determine species richness (Spellerberg and Sawyer, 1999). Recent studies have demonstrated